

## GEOMETRICAL DESIGN OF STAND PIPE AIR DISTRIBUTORS FOR THE COMBUSTION OF MUNICIPAL SOLID WASTE IN A FLUIDISED BED

ANWAR JOHARI<sup>1\*</sup>, H. HASHIM<sup>2</sup> & M. ROZAINEE<sup>3</sup>

**Abstract.** The new geometrical design of stand-pipe air distributor for the combustion of the municipal solid waste was presented. The new design of the air distributors enables penetration of incombustible and unburnt carbon through opening between the air distributors, thus providing easy maintenance work. The fluidized bed experimental rig was constructed using Perspex column in which air was supplied through the distributors below it. In order to establish the final geometrical design of the air distributors, several design parameters were investigated. The effect of orifice size, distance between orifice and distance between distributor pipes on the fluidization behaviour were studied. Investigation on the effects of various orifice sizes of 1.5 mm, 2 mm, 3 mm, 4 mm and 5 mm showed that the 3 mm orifice size exhibited the most stable fluidization behaviour. Investigation on some selected orifice distances of 10 mm, 20 mm, 30 mm and 40 mm also found that the 10 mm orifice distance exhibited stable growths of bubbles. Various pipe distances of 30 mm, 40 mm, 50 mm, 60 mm and 70 mm were also investigated and the most suitable pipe distance was 70 mm.

**Keywords:** Air distributor; fluidized bed; orifice size; orifice distance; pipe distance

**Abstrak.** Reka bentuk geometri bagi penyalur udara untuk pembakaran sisa buangan sampah perbandaran telah dihasilkan. Reka bentuk baru ini membolehkan bahan tidak terbakar dikeluarkan dengan mudah melalui ruang antara penyalur udara. Turus terbendalir dihasilkan menggunakan turus Perspex di mana udara disalurkan melalui penyalur udara di bawahnya. Untuk mendapatkan reka bentuk geometri yang sesuai, beberapa parameter reka bentuk telah dikaji. Kesan saiz bukaan, kesan jarak antara bukaan dan kesan jarak antara penyalur udara telah dikaji untuk mendapatkan reka bentuk geometri yang paling sesuai dan berdasarkan kepada kualiti perbendaliran di dalam turus terbendalir. Saiz bukaan yang dikaji adalah 1.5 mm, 2 mm, 3 mm dan 5 mm. Hasil kajian menunjukkan bukaan 3 mm menghasilkan kualiti perbendaliran yang stabil. Jarak antara bukaan yang dikaji adalah 10 mm, 20 mm, 30 mm dan 40 mm dan didapati buih udara yang terhasil adalah stabil apabila menggunakan jarak antara bukaan 10 mm. Jarak antara penyalur udara yang dikaji adalah 30 mm, 40 mm, 50 mm, 60 mm dan 70 mm. Hasil kajian menunjukkan jarak terbaik dari segi kestabilan buih udara bagi penyalur udara adalah 70 mm.

**Kata kunci:** Penyalur udara; turus terbendalir; saiz bukaan; jarak antara bukaan; jarak penyalur udara

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<sup>1,2&3</sup> Department of Chemical Engineering, Faculty of Chemical and Natural Resources Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor Bahru, Malaysia

\* Corresponding author: Tel: 607-5535554, Fax: 607-5581463. Email: anwar@fkkksa.utm.my

## 1.0 INTRODUCTION

The types of gas distributor have a significant influence on the behaviour of the fluidised bed. The function of the distributor is to provide a uniform flow of small bubbles to enhance mixing. It should be able to operate without blocking and preventing backflow of solids into the windbox. The common designs for the laboratory purpose are porous and perforated plates. Geldart and Baeyens [1] reviewed some of commonly used air distributors. They pointed out critical factors influencing the effective design of the distributors. Among them were pressure drop ratio (ratio of pressure drop across the distributor to that of the bed), orifice size, geometry and spacing as these factors influenced the jet penetration, dead zones and bubble formation.

Saxena *et al.* [2] reported the effect of distributors on gas-solid fluidisation. Distributors used in the investigation were porous plate, two bubble cap distributors of different geometries and others. They concluded that the pressure drop across these distributors was found to increase with fluidising velocity and to be independent of the bed weight or height. They also found out that the smaller the percentage open area of air distributor led to higher pressure drop than necessary for smooth fluidisation and would require greater energy consumption for its operation. In view of suitable pressure drop for the fluidised bed operation, Qureshi and Creasy [3] mentioned that many pilot scale plants operated at pressure drop ratio as high as 0.4. However, this is relatively accepted if high pumping cost is not taken into serious consideration. They proposed the maximum value of 0.21, which applies for shallow beds.

According to Leung [4] the bubble size distribution depends to some extent on the orifice spacing of the distributor plate. Werther [5] also examined the influence of the distributor design on bubble characteristics. The experiments were conducted using eight different gas distributors, which differed in their designs and orifice openings and arrangements. Results suggested that each distributor showed different bubble characteristics, therefore significantly affected the mixing characteristics as a whole. Hsiung and Grace [6] reported that at high gas velocities through small orifices, jets or spouts formed at many or all the orifices with bubbles detaching from the ends of these jets or spouts. Thus, this resulted in an increased grid height (jet height), or in another word, increased the maximum vertical length of the jet. It is over this height that the dense phase is well fluidised. According to Wen *et al.* [7] several factors such as gas velocity, distributor type, orifice interval and diameter and particle size have significant effects on the dead zone region. They concluded that the dead zones decreased in height as the gas flow was increased. Feng *et al.* [8] studied the effect of different orifice configurations on the formation of bubble and solid mixing and found out that the dead zone on the grid could be improved with the use of larger number of orifice and smaller orifice distances. They also pointed out that the uniformity of the fluidisation could be improved when operating velocity

was increased. For lower air flow rates, the dead zone could be eliminated through the use of smaller orifice interval. Increasing the orifice diameter resulted in smaller dead zone heights for the same orifice distance.

Sathiyamoorthy and Rao [9] examined the performance of a 100 mm diameter glass column using multi-orifice distributors and concluded that the performance of the distributor was strongly influenced by the bed height, bed material, number of orifice and geometry of their location. Other authors such as Upadhyay and Saxena [10] and Saberi *et al.* [11] concentrated their efforts on studying the effect of holes geometrical location and number of holes and its diameters in maximising the full performance of the distributor. Bauer and Werther [12] studied the influence of types of distributors on mass transfer and chemical reactions. The gas distributors employed in the investigation were porous plate, perforated and nozzle plates with different openings and diameters. Results showed that for porous plate, the conversion was much better than the perforated plates as porous plate provides a very fine dispersion of the reaction gas. Perforated plates with smaller orifice diameter also yielded better conversion. Sathiyamoorthy and Horia [13] studied the influence of multi orifice air distributors on the fluidization of homogeneous materials of alumina, rutile and zircon. Two types (A and B) of multi orifice distributor having free open area of 0.273% and 0.52% were used. The numbers of orifices and diameter were 121 and 0.95 mm respectively for type A distributor whereas the numbers of orifices and diameter of type B were 325 and 0.8 mm respectively. Paiva *et al.* [14] reported the influence of the distributor plate on the fluidising behaviour of the Group B silica ballottini having a size range of 0.355 – 0.425 mm. Three types of distributors were used namely porous ceramic, metallic mesh and perforated perspex.

Most of the literature reviews focussed on the design of the porous and perforated plates. The porous and perforated plate distributors have been used in small laboratory fluidized bed. These two air distributors are more suitable for the combustion of homogeneous waste material of biomasses such as rich husk and wood chips. The current research activities have been focussing on the new geometrical design of the air distributor for the combustion of municipal solid waste in a fluidised bed. Porous and perforated air distributors are not suitable for the combustion of municipal solid waste since the composition of municipal solid waste is heterogeneous in nature and contains size and shape of different sizes. The new design enables the penetration of incombustibles and partially burnt materials through opening between the air distributors and allows easy maintenance.

## 2.0 EXPERIMENTAL PROCEDURES

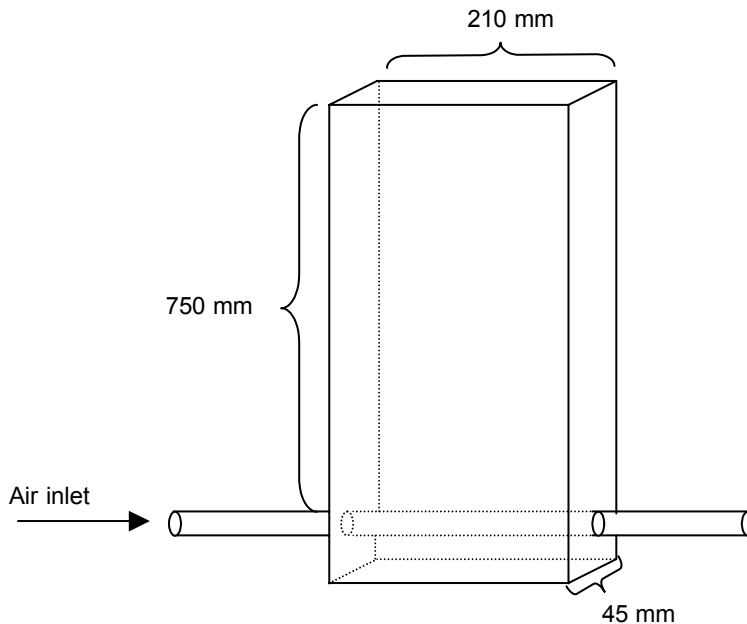
Experimental rig of standpipe air distributors was first set-up using Perspex column. Parameters under investigation were the effect of orifice diameter, orifice distance and distance between pipes on the fluidization behaviour. The distributor pipes

were fabricated by galvanized iron pipe with 20 mm internal diameter. The scope of work comprises:

- (i) Single orifice study – the use of various orifice diameters of 1.5 mm, 2 mm, 3 mm, 4 mm and 5 mm in order to obtain the optimum orifice size for good mixing and fluidization. Result gained in this test was used as a design parameter for further test.
- (ii) Orifice distance study – the use of various orifice-to-orifice distances of 10 mm, 20 mm, 30 mm and 40 mm in order to establish the most optimum distance between orifices for good fluidization. The orifice diameter was set based on findings from single orifice study.
- (iii) Pipe distance study – the use of various pipe distances of 30 mm, 40 mm, 50 mm, 60 mm and 70 mm for the determination of the optimum pipe distance between each other. The optimum orifice size and distance was determined earlier.

## 2.1 Single Orifice Study

Orifice with different diameters was drilled at the centre of pipe in each case study to investigate its effect. Orifice diameters under investigation were 1.5 mm, 2 mm, 3 mm, 4 mm and 5 mm respectively. The dimension of the column was chosen at 210 mm × 45 mm × 750 mm as shown in Figure 1.



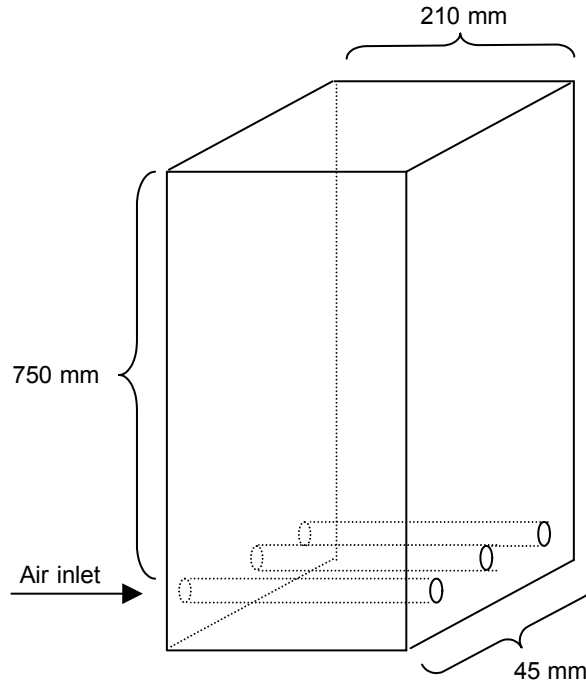
**Figure 1** Single orifice study

## 2.2 Orifice Distance Study

Effect of distance between orifices on the bubbling behaviours was investigated. The orifice distance drilled were 10 mm, 20 mm, 30 mm and 40 mm respectively. The column dimensions were maintained as the same as previous experiments and the height of the sand bed was also remained at 450 mm. The orifice diameter was fixed at the optimum value obtained in the earlier experiment. Air up to 150 litre/minute was introduced into the bed through the orifices.

## 2.3 Pipe Distance Study

The optimum distance between pipes was studied to determine the uniform and stable fluidisation. The optimum value of orifice diameter and orifice distance were 3 mm and 10 mm respectively, determined from the earlier studies. Three stand pipes with internal diameter of 20 mm then were drilled with 3 mm orifice diameter and at a distance of 10 mm apart. The choices of pipe distance studies were 30 mm, 40 mm, 50 mm, 60 mm and 70 mm apart. The bed height was fixed at 210 mm and air was introduced into the bed at 300 LPM and 500 LPM respectively. A rectangular Perspex column was constructed having a dimension of 210 mm  $\times$  210 mm  $\times$  750 mm. Figure 2 shows the experimental layout.



**Figure 2** Experimental layout in determining the optimum pipe distance

### 3.0 RESULTS AND DISCUSSION

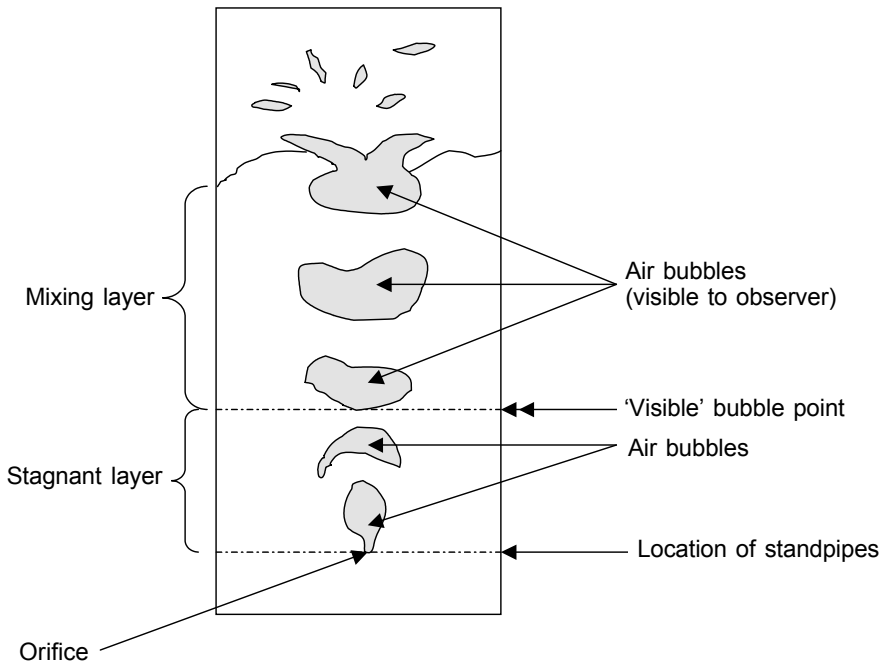
#### 3.1 Effect of Orifice Diameter

The purpose of using only a single orifice was to enable the tracking of a single bubble in terms of its formation and effect on the overall bed fluidization behaviour. Air was gradually introduced into the bed until the bubbles were formed and a continuous chain of bubbles could be observed (air flow rates of up to 70 LPM). The sand bed height was fixed at 450 mm in all cases. Initial testing with a lower sand bed height, such as 200 mm proved insufficient for a complete tracking of bubbles, as the high velocity air jet from the orifice tend to penetrate to the surface of the bed, thus creating a spout-like air jet similar to the profile of a spouted bed. It was hypothesized that larger orifice will tend to provide more turbulence in the bed due to the formation of larger bubbles, and hence, larger orifice is preferable. However, there is an upper limit to the diameter of the orifice at which the bed will behave as a fluidized bed. Orifice large enough to provide low air jet velocity will result in the air percolating through the bed instead of suspending the bed particles, thus diminishing the fluidized state of the bed.

The spout-like behaviour was observed regularly from an orifice diameter of 1.5 mm but occasionally bubbles formed had a fairly constant size of 50 – 70 mm. A continuous chain of bubbles could not be obtained despite efforts to increase the airflow. Nevertheless, with careful manipulation of the air flow rates, the profile of the bubble from its growth until it was ‘visible’ at some distance above the orifice could be observed. This phenomenon happened occasionally and thus the fluidization was regarded as very poor.

With an orifice diameter of 2 mm, it was observed that the turbulence inside the bed was low. A continuous chain of bubbles was formed, and these bubbles were ‘visible’ at a fairly constant height of 150 – 200 mm above the orifice. Observations of the bubbling behaviours showed that the bed could be divided into two distinct zones, namely stagnant and mixing zones. The stagnant zone originated from the stand pipe to a certain bed height whilst mixing zone was observed above the stagnant zone where bubbles were ‘visible’. At the stagnant layer, the bed particles around the bubble formation area were observed to be slowly moving downwards to fill in the voids created by the bubbles. The stagnant layer was very high (150 – 200 mm). In the mixing zone, bubbles were visible and could be observed. Figure 3 characterizes the two distinct zones in the Perspex column using single orifice on the stand pipe.

Bigger bubbles were observed (50 – 100 mm) when the orifice diameter was increased to 3 mm. With the increasing air flow, it was observed that the stagnant layer was lowered to a range of 150 – 180 mm resulting in an increase in the mixing zone. The degree of sand circulation in the bed was good and more turbulent compared to that of 2 mm orifice diameter case study. In the case of 4 and 5 mm orifice diameter, bubbles could still be observed and the stagnant bed height remained



**Figure 3** Stagnant and mixing zones in the perspex column of fluidized bed single orifice study

constant at about 200 – 250 mm. This resulted in the reduced height of the mixing zone which was not preferable for optimum mixing criteria. The phenomenon was probably due to the formation of very large bubbles (70 – 100 mm) which tend to burst at higher flow rates. Another drawback of using these two orifice sizes were the effect of sand clogging on the orifice. Table 1 summarizes the effect of the orifice diameter on the bed behaviour.

Therefore, orifice diameters of 2 mm and 3 mm were observed to produce more stable and continuous formation of bubbles which in turn led to a good mixing behaviour.

**Table 1** Effect of stand pipe orifice diameter on the fluidization behaviour in a single orifice study

Orifice diameter(mm)	Bubble size (mm)	Stagnant height (mm)	Fluidization behaviour
1.5	50 – 70	Not applicable	Poor
2	50 – 70	150 – 200	Good with some degree of mixing observed beyond bubble 'visible' point and but some spout-like behaviour
3	50 – 100	150 – 180	Good mixing behaviour, more turbulent than the case of 2 mm orifice size
4	70 – 100	200 – 250	Good but tends towards channeling
5	80 – 100	200 – 250	Channeling

### 3.2 Effect of Orifice Distance

The effects of orifice-to-orifice distance on the bubbling behaviour were summarized in Table 2.

It was found that the mixing was good with low stagnant heights (less than 120 mm) for the bed using stand pipe with orifice-to-orifice distances of 10 mm and 20 mm. However, bubbles formed from the former were more stable in size, growing to a fairly constant size of 50 mm. However, in the case of the latter subjects, bubbles were not stable in size and sometimes capable of reaching a diameter of about 100 mm. Therefore, 10 mm orifice-to-orifice distance was chosen as the optimum design criteria.

**Table 2** Effect of orifice distance

<b>Orifice-to-orifice distance (mm)</b>	<b>Stagnant height (mm)</b>	<b>Mixing layer (mm)</b>	<b>Observation(s)</b>
10	80 – 100	350 – 370	Stable bubble growth ranges from of 30 – 40 mm in diameter (at bed height of 100 mm) to a stable size of approximately 50 mm. Formation of continuous chain of bubbles. Turbulent mixing above the stagnant layer
20	100 – 120	330 – 350	Stable and continuous chain of bubbles observed to be formed from a bed height of approximately 100 mm. Size of bubbles increase from approximately 50 mm (at bed height 100 mm) to approximately 100 mm. More intense mixing above stagnant layer due to occasional formation of larger bubbles (>100 mm)
30	130 – 150	300 – 320	Bubbles grow from about 80 mm to 100 mm. Good mixing above stagnant layer
40	170 – 200	250 – 280	Size of bubbles fairly constant at approximately 100 mm. Mixing not very good as the bed tends towards slugging mode. Significant channeling behavior at mixing layer

### 3.3 Effect of Pipe Distance

The effects of orifice-to-orifice distance on the bubbling behaviors were summarized in Table 3.

From the experiment, it was found that the standpipes distances of 50 mm and above showed good and uniform fluidization behaviour for both air flow rates with



**Table 3** Effect of pipe distance on the bubbling behaviours

<b>Distance between pipe (mm)</b>	<b>Flow rate (LPM)</b>	<b>Stagnant height (mm)</b>	<b>Observation(s)</b>
70	300	80-90	Good and uniform fluidization above the stagnant layer
	500	50	
60	300	80	Fluidization behaviour similar to the above (70 mm distance between pipes)
	500	50	
50	300	50	Stagnant layer thinner, uniform fluidization above stagnant layer but mixing more turbulent
	500	40	
40	300	40	Stagnant layer very thin, mixing more vigorous above stagnant layer
	500	30	
30	300	40	Stagnant layer not very pronounced. Bed behaved almost like a spouted bed. Frequent formation of bubbles with size of about 50 mm at mixing layer. Sand particles splashed up to 200 mm above the bed

70 mm distance apart was seen as the most suitable design criteria. Therefore, 70 mm distance between pipes was chosen as a design criterion.

Final design of the distributor of fluidized bed for combustion of simulated municipal solid waste is shown in Table 4 below.

**Table 4** Final distributor design dimensions

<b>Orifice diameter (mm)</b>	<b>Orifice distance (mm)</b>	<b>Distance between pipe (mm)</b>
3	10	70

## 4.0 CONCLUSION

Geometrical design of stand-pipe air distributors was presented. The most suitable orifice diameter was 3 mm. Orifice diameters smaller than 3 mm exhibited spout-like behaviour which is not desirable for mixing and sand circulation in the fluidized bed whereas, orifice diameters of more than 3 mm showed large bubble formations and towards channeling. Orifice distance of 10 mm was found to give the most satisfactory results as bubbles formed were not too big and stable in size. The distance between pipes was chosen at 70 mm apart as at this distance the fluidization was observed to be uniform and well continuous bubbles formation.

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